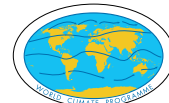


CLIVAR

The Principal Research Areas D5: Southern Ocean Climate Variability



Goal:

Improving the description and understanding of the variability of the Antarctic Circumpolar Current, ocean overturning and water mass transformations in the Southern Oceans.

Introduction

The Southern Ocean is of crucial importance for the global climate system because:

- The Southern Ocean helps shape the global ocean stratification;
- It plays a unique role in coupling the ocean to the atmosphere and cryosphere; and
- It plays a central role in global sea level.

Variations in these aspects of the global climate system may be expected to be linked to and perhaps drive global climate variability.

Variability in the formation and spreading of Southern Ocean water masses and their inter-ocean communication is very likely associated with climate variability.

Changes in Deep Sea Temperature

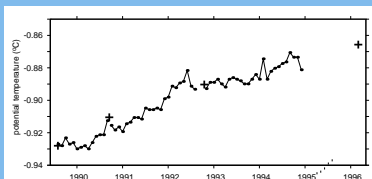


Fig. 1: Potential temperature in the central Weddell Sea (65°37'6.5, 36°29'4W) measured 50 m above the sea floor in a water depth of 4740 m with moored instruments (dots for monthly mean values) and with conductivity-temperature-depth (CTD) sondes (crosses). The temperature increase in the bottom water layer coincides with warming of the water masses entering into the Weddell Sea from the Antarctic Circumpolar Current (from Fahrbach et al., 1998, J. Geophys. Res., submitted).

The Antarctic Circumpolar Wave

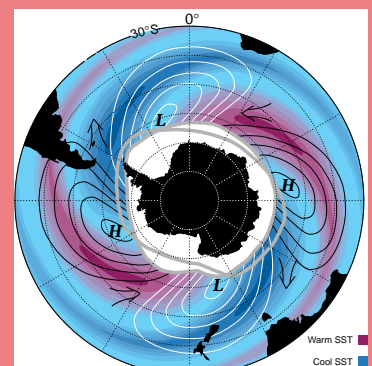


Fig. 2: Simplified schematic summary of interannual variations in sea surface temperature (red: warm, blue: cold), atmospheric sea-level pressure (bold H and L), meridional wind stress (denoted by the arrow), and sea-ice extent (grey lines). Sea ice extent is based on an overall 15-year average (after White and Peterson, 1996).

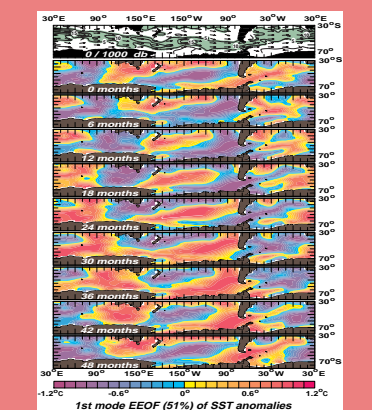


Fig. 3: Top panel, surface geostrophic velocity vectors relative to 1,000 db (~1,000 m depth) calculated from new atlas data. Eastward components of >5cm/s-1 are shaded. Lower nine panels: lag-sequences of the dominant mode of an extended EOF analysis of interannual anomalies of SST, which in this case accounts for 51% of the total SST variance for the ten-year period of 1985-94. The extended EOF is computed from the covariance of state vector for standardized interannual SST anomalies, yielding estimates with equal variance over the field. This allows propagation to be seen unbiased by regions of strong and weak variance. Contour intervals for the lag-sequences of SST is given by the colour bar, ranging over +/- 1.2°C (White, B.W. and R.G. Peterson, 1996, Nature, 380, 699-702).

Scientific rationale

Specific Southern Ocean climate foci include:

1. The Antarctic Circumpolar Current and its role in the global ocean circulation.
2. The Southern Ocean coupling of the ocean and atmosphere within the subtropical belt and its polar-extrapol communication of heat, freshwater and CO₂ through the production of Antarctic Intermediate Water and Subantarctic Mode Water.
3. Upwelling of Circumpolar Deep Water poleward of the Antarctic Circumpolar Current provides the site for major venting of deep oceanic heat into the atmosphere and associated cryosphere (sea ice and its polynyas (Fig. 1) and glacial shelf ice), it may also influence sea level as a result.
4. The production of the very cold dense Antarctic Bottom Water which dominates the lower two kilometres of the global ocean.
5. The Antarctic sea ice fields that represent a highly mobile and mutable surface property whose distribution and characteristics may play a major role in the global radiative budget and thus global climate.
6. The large-scale coherent variability of the atmospheric circulation over the Southern Ocean and the mechanisms of these variations and their geographic communication, are directly involved in the propagation of anomalies across the various climate zones.

For practical considerations not all of the Southern Ocean climate related issues can be covered by CLIVAR research. A subset is selected that is considered as important and for which significant progress can be expected. The scientific rationale summarised above can best be addressed by focusing on four phenomena:

1. Variability in the Antarctic Circumpolar Current, including the Antarctic Circumpolar Wave: physical mechanisms and low-latitude connection (Fig. 2 and 3).
2. Variability in the formation, circulation and atmospheric feedback of Sub-Antarctic Mode Water and Antarctic Intermediate Water (Figs. 4 and 5).
3. Variability in deep water upwelling and bottom water formation (overturning cell) and the coupled response of sea ice distribution, glacial ice and the atmosphere, including variability in sea ice extent, thickness and divergence; and coupled ice-ocean-atmosphere interactions, including the possibility of abrupt change (Fig. 6).
4. Formation mechanism of Antarctic Bottom Water (Fig. 1).

Observations

The following key observations have been identified for a research programme on Southern Ocean Climate Variability:

- Chokepoint monitoring between Antarctica and the other Southern Hemisphere continents to monitor fluxes associated with the ACC between the three ocean basins.
- Mid-latitude zonal sections measuring meridional fluxes of mass, heat and salt to determine the connection of the circumpolar water belt to the three major ocean basins.
- Periodic (~5 year) repeats of selected additional deep hydrographic lines.
- Additional XBT/XCDT sampling on VOS where practical.
- Salinity sampling: PALACE floats to monitor T(z), S(z) and the circulation.
- Surface drifters (including drifters in the sea ice zone).
- Deep boundary current measurements to monitor the formation of Antarctic Bottom Water.
- Satellite monitoring of SST, sea level, winds and sea ice.
- Ice and snow thickness.
- Monitoring of fast ice thickness at key sites.
- Combination of moored measurements and "rapid response" cruises, e.g. if there are indications of a recurrence of the Weddell polynya.

Changes in Water Mass Properties

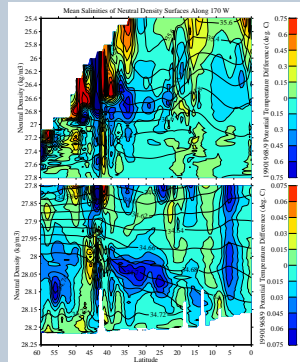


Fig. 4: Vertical section of salinity means and potential temperature differences on neutral density along 170°W using the 1950 and 1980/9 data. The top panel shows salinities from about 200 m of the sea surface to a mean depth of about 1500 m. The bottom panel shows the deeper salinities on an expanded vertical scale. The mean salinity contours (thick line) are contoured at 0.2 ps intervals in the upper panel and 0.02 ps intervals in the lower panel. Potential temperature difference contours of 1990-1980/9 (thin line) are contoured at 0.15°C intervals in the upper panel and 0.015°C intervals in the lower panel. Blue areas show where water has cooled (and freshened) on neutral densities over the 21-year interval. There is substantial and widespread cooling in the sub-tropical gyre between 40°S and 20°S just above the Antarctic Intermediate Water salinity minimum. In the top panel and measurable cooling between the Chatham Rise at 43°S and the Samoan Passage at 10°S just above the modified North Atlantic Deep Water salinity maximum in the bottom panel. The figure is a colour version of Fig. 4 from Johnson and Orr (1997, J. Climate, 10, 306-316).

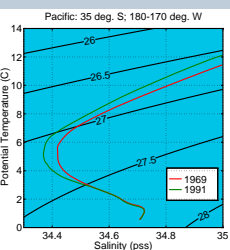


Fig. 5: Mean potential temperature-salinity curves in the Southwest Pacific Ocean along 35°S between 180° and 170°W in 1989 (red line) and 1991 (green line) using data discussed in Johnson and Orr (1997, J. Climate, 10, 306-316). Potential densities are contoured. Similar results are found in the Tasman Sea (Bindoff and McDougall, 1994, J. Phys. Oceanogr., 24, 1137-1152) and in the Indian Ocean (Bindoff and McDougall, 1997, J. Climate, in press). The cooling and freshening on isopycnals in the range of the Antarctic Intermediate Water and the Sub-Antarctic Mode Water is similar in magnitude to, but much more widespread than, changes reported over a similar time interval in the North Atlantic (Byden et al., 1996, J. Climate, 9, 3162-3186).

The Weddell Sea Polynya

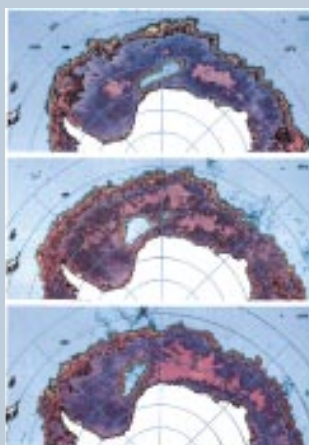


Fig. 6: Weddell Polynya: An enormous ice-free region amid the ice cover near the Weddell Sea formed during three consecutive Southern Hemisphere winters. In these satellite images, which were made in September of 1974 (top), 1975 (middle) and 1976 (bottom), the white region represents the Antarctic landmass and grey shaded regions represent ocean areas covered by various concentrations of sea ice. Dark grey regions are almost completely covered by ice and light grey regions are ice-free. In summer the polynya disappeared with the melting of the ice cover. At its largest the polynya measured about 350 by 1000 kilometres. It had measurable effects on the temperature of the underlying ocean at depths as great as 2500 metres (from Gordon and Comiso, 1988, Scientific American, 90-97).

Modelling

A hierarchy of models is required in order to address properly the range of issues spanning a variety of space and time scales, and differing degrees of complexity.

Global circulation model studies

The lack of observations in the Southern Ocean means that documenting patterns of variability is difficult. In this context, AGCMs driven with imposed SST or ice anomalies at their lower boundary have a role in elucidating the sensitivity of the climate system to Southern Ocean anomalies. Similar experiments with OGCMs would assist in developing hypotheses as to the nature and impact of oceanic teleconnections between high and low latitudes.

The response of coupled climate models to increasing atmospheric CO₂ concentrations has been shown to be sensitive to the representation of Southern Ocean sea ice, mixing and circulation.

Regional model studies

Regional models are required to better determine which processes are critical to the regional evolution, and therefore must be properly parameterised in the GCMs. Such models are essential to the study of specific processes and sensitivities involved in: deep and intermediate water formation and their flow rates and paths; regional preconditioning of the polar gyres and their sensitivity to convective overturn; glacial ice-ocean interaction, particularly its influence on the stability of the ice sheet and sea level; gyre scale ocean-ice interaction and its influence on the ice distribution in space and time; communication of properties between polar and sub-tropical regions and its sensitivity; and other such processes thought to be critical in the Southern Ocean's influence on climate.

Local process models

Local process models are required to explicitly target individual processes or phenomena in an effort to determine the relative control by competing processes, appropriate sub-grid scale parameterisation schemes, critical sampling intervals and scales, and sensitivities to changes in the forcing and initial conditions.

The Cryosphere

An Important element in the Climate System



The Southern Ocean CLIVAR programme will have to link closely with other existing resp. planned programmes active in cryospheric research, such as the Arctic Climate System Study (ACSYS), the SCAR GLOCHANT initiative and the International Programme for Antarctic Buys (IPAB), the Antarctic Ice Thickness Research Programme (AntITRP), and the International Antarctic Zone Programme (IAZONE) as well as with the proposed new WCRP Cryosphere and Climate project.

Photos: upper left: The German research vessel in sea ice (courtesy of T. Martin), upper right: Antarctic sea ice (courtesy of U. Wuytack), lower left: decay of sea ice in spring (courtesy of A. Villwock), lower right (shelf ice edge during the Austral summer (courtesy of G. König-Langlo).

Cross linkages within other CLIVAR PRA's

This research project is closely related to the following CLIVAR PRA's:

